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Canada Centre for Mineral and Energy Technology | Centre canadien de la technologie des minéraux et de l'énergie

# THERMAL CONDUCTIVITY OF CREIGHTON MINE ROCKS

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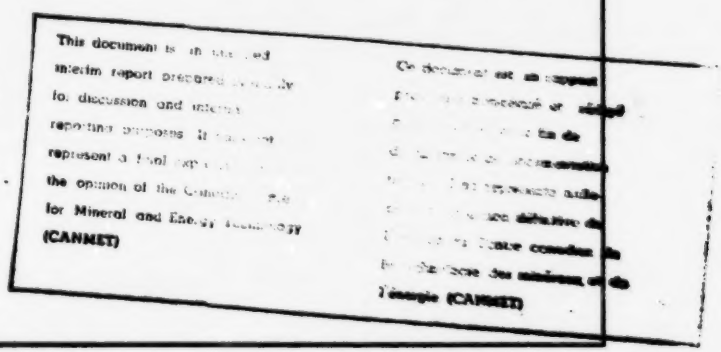


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# THERMAL CONDUCTIVITY OF CREIGHTON MINE ROCKS

by

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## ABSTRACT

The thermal conductivity of two groups of rock specimens, a total of nine rocks, from the Creighton Mine, Sudbury, Ontario, was measured in the temperature range of 100° to 500°C. The thermal conductivities are required for estimation of the temperature profiles in the rock mines surrounding a heating testing installation and to predict the relative thermal stability of the host rock. The differences in thermal conductivity between the individual rocks are not very large. However, for seemingly identical specimens, the average thermal conductivity of the CB-drill core specimens is somewhat higher than that of the CA-drill core specimens. The most significant fact for all the Creighton Mine specimens used in these measurements is that the thermal conductivity of all the specimens decreases surprisingly little with increasing temperature and that in some cases it actually increases above 350°-400°C.

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## INTRODUCTION

After being discarded from a nuclear reactor, the spent fuel rods remain radioactive for centuries and must be therefore disposed of safely. The spent nuclear fuel generates appreciable quantities of heat for 15 to 20 years, the effect of which on the material of the repository must be taken into consideration in the selection of the storage site.

In the case of a rock repository, thermal conductivity is an important thermophysical parameter because it establishes (in the steady-state configuration) the rate at which heat from the waste radioactive products would be dissipated through the rock mass. Its absolute value and the rate of change of this value with temperature provides a sensitive measure for evaluation of the thermal stability of different rock masses.

Thermal conductivities of many rocks were measured in the past. A fairly comprehensive review of the published results was recently made by Horai[1]. Unfortunately, because of their very complex nature - the wide variations in composition and texture - the description of rocks is seldom adequate and the thermal conductivity of a particular rock cannot be established with confidence from published data but has to be determined through measurements.

To facilitate evaluation of different rock types under various heat loads, in-situ thermal modeling experiments are to be conducted in a representative Canadian rock mass, conveniently available at the Creighton Mine of the International Nickel Corporation of Canada. To facilitate correlation of experimental and calculated values, the thermal ~~diffusivity~~ conductivity of 9 rock specimens from the Creighton Mine was measured between 100° and 500°C.

## PROCEDURES

### (a) Method of measurement

The thermal conductivity measurements were performed in a comparative-method thermal conductivity apparatus, described in detail previously[2]. In essence, a 1-inch diameter rock specimen, 1-inch high is placed between two standards of the same dimensions. The column consisting of the three cylinders is placed on a cylindrical heat stabilizer, which is of the same dimensions and is made of the same material as the standards and held between the heat source and heat sink. The entire assembly is surrounded by a cylindrical heat guard. By adjusting the power input to the guard heaters wound on the outside of the heat guard, aerial heat flow axial only can be maintained. Under such conditions the temperature gradients in the cylinders will be inversely proportional to thermal conductivity and as the conductivity of the standards is known, the thermal conductivity of the specimen can be readily calculated.

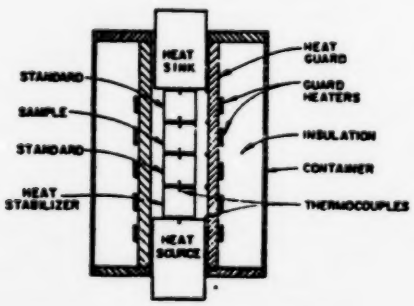


Figure 1. Thermal conductivity apparatus schematic.

Temperatures were measured with 28 B&S gauge chromel-alumel thermocouples. Pyroceram Code 9606* was used for the standards and the heat stabilizer. All measurements were made at successively increasing temperatures. The temperature gradients within the rock samples were between 15° and 24°C. The accuracy of the measurements is estimated to be ±5%.

(b) Materials

The rock samples for this study were obtained from two drill cores extracted from the 'Main Mass' norite near No. 9 mine shaft on level 2300 of the Creighton mine near Sudbury, Ontario. Nine samples were selected and characterized by Soles[3]. Four rocks were taken from drill core CA and five from drill core CB.

Examination of the specimens revealed that all nine rocks are quartz diorite. The specimens are compositionally very similar and the variations in texture and structure are small. The texture of all samples is hypidiomorphic granular with grain size of various minerals mostly in the 0.01- to 5.0-mm range. Joints and hairline fractures are widely spaced. Shears are rare and intergranular fracturing uncommon. Table 1 gives the composition ranges for the two groups of rocks.

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* Manufactured by Corning Glass Works, Corning, New York, U.S.A.

TABLE 1

Composition of Creighton Mine Rock Specimens[3]

| Mineral | Volume percent range | |
|---|---|---|
| | CA | CB |
| Plagioclase (An) | 40-47 (38-43) | 38-43 (38-43) |
| Amphibole | 27 - 31 | 15 - 31 |
| Quartz | 9 - 12 | 9 - 16 |
| Biotite | 8 - 15 | 10 - 15 |
| Green Mica, Chlorite | 1 or less | < 1 |
| Scapolite | 1 - 6 | 1 - 11 |
| Ilmenite, Magnetite | 1 - 3 | 0.5 - 2 |
| Apatite, Epidote, Calcite, etc. | <.5 | <.5 |

(An) = percent Anorthite content.

The specimens used for these measurements were prepared in the form of 1-inch diameter, 1-inch high cylinders. They were ground to a tolerance of ±0.001 inch. Each cylinder was provided with two 0.03-inch diameter thermocouple holes, which were drilled radially from the surface to the cylinder's axis at a distance of 0.05 inch from each end.

## RESULTS AND DISCUSSION

The results of the thermal conductivity measurements are shown in Figures 2 and 3. The curves were fitted to the data by the least squares method. Each curve represents 8 to 10 conductivity measurements. The curves are also expressed by equation:

$$\lambda = a_1 + a_2 t + a_3 t^2$$

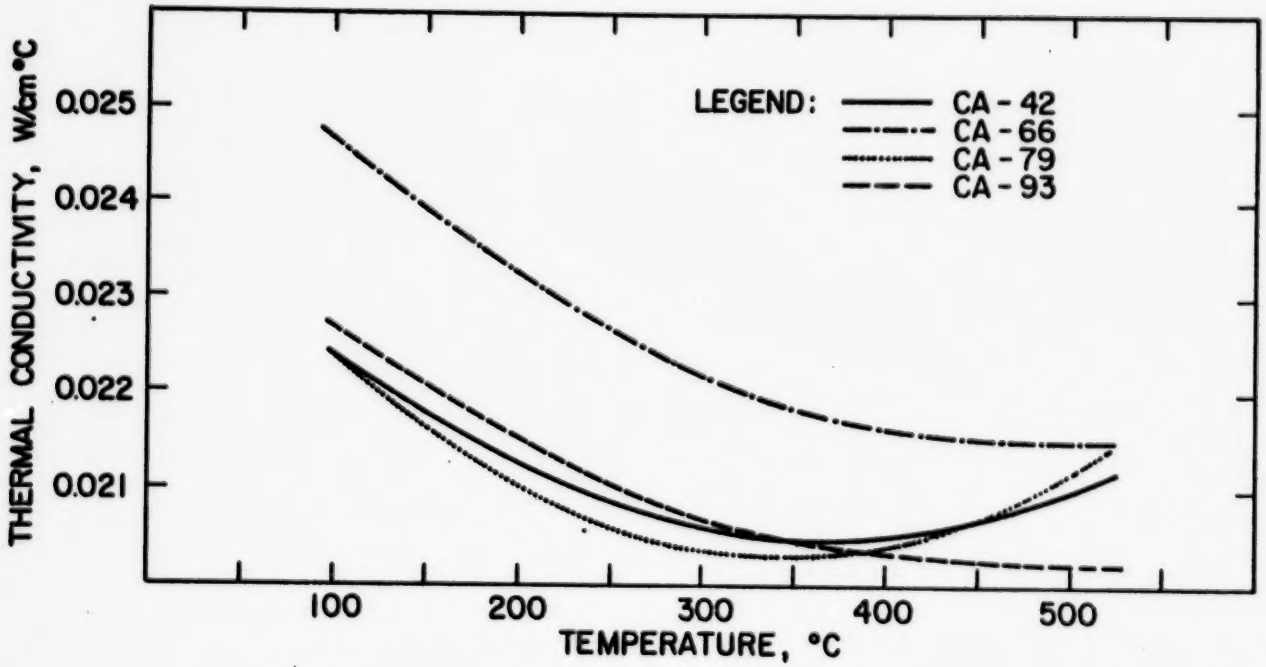


**Figure 2.** Thermal conductivity of four rocks from Creighton Mine, drill core CA.

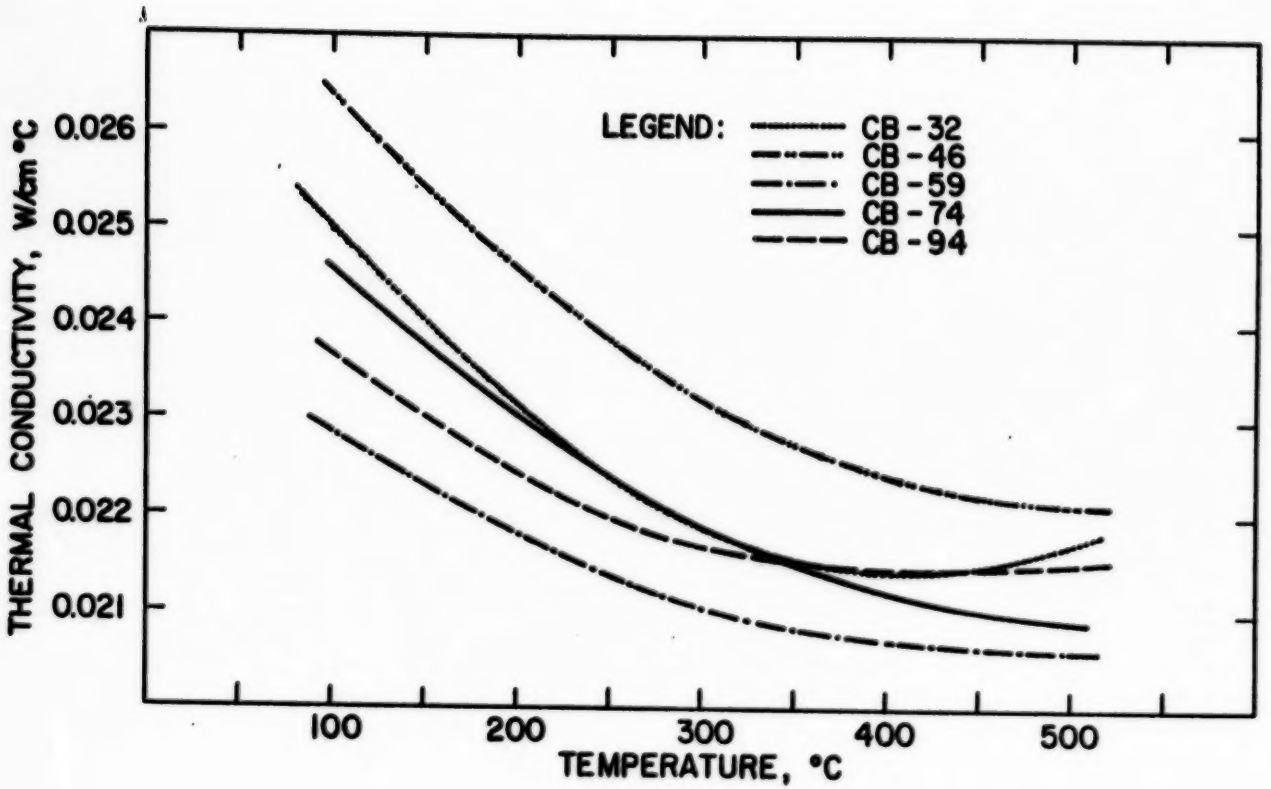


Figure 3. Thermal conductivity of rock specimens from Creighton Mine, drill core CB.

where $\lambda$ is the thermal conductivity in watt/cm°C and t is temperature in °C. The equation is valid for the temperature interval of 100° to 500°C. It should be permissible, however, to extend its range by 50°C above and below the stated temperature limits. The coefficients $a_1$, $a_2$ and $a_3$, as well as the standard and average deviations are given in Table 2.

TABLE 2

Coefficients for the Least Squares Polynomial and Standard and Average Deviations

| Rock Specimen | Coefficients | | | Deviation (W/cm°C) x$10^4$ | |
|---|---|---|---|---|---|
| | $a_1 x10^2$ | $a_2 x10^5$ | $a_3 x10^8$ | Standard | Average |
| CA-42 | 2.451 | -2.459 | 3.575 | 1.6 | 1.5 |
| CA-66 | 2.664 | -2.196 | 2.332 | 2.5 | 2.1 |
| CA-79 | 2.410 | -2.003 | 2.775 | 1.4 | 1.9 |
| CA-93 | 2.420 | -1.713 | 1.826 | 1.5 | 2.6 |
| CB-32 | 2.764 | -2.985 | 3.576 | 2.2 | 3.6 |
| CB-46 | 2.866 | -2.568 | 2.501 | 2.0 | 3.4 |
| CB-59 | 2.421 | -1.569 | 1.712 | 1.3 | 2.8 |
| CB-74 | 2.628 | -1.991 | 1.819 | 4.0 | 2.8 |
| CB-94 | 2.511 | -1.773 | 2.089 | 1.2 | 2.4 |

Because none of the samples had identifiable schistosity, no attempt has been made to relate thermal conductivity to the orientation of the sample in the drill core.

Figure 2 shows the data for the four samples from the CA drill core. At lower temperatures the thermal conductivities of rocks CA-42,-79 and -93 are bunched together with little differentiations between each other up to about 300°C. Above this temperature, however, the thermal conductivities of CA-42 and -79 begin to increase. Such behaviour is very unusual as heat

transport in non-conductors at these temperatures is almost exclusively by lattice vibrations. One would expect that at progressively higher temperatures, the microcracks and fractures would tend to increase in size and number and thereby reduce the transport ability of the rock. Of course, the possibility of a measurement error cannot be excluded. However, considering that at least one rock in the CB group (CB-32) also exhibits an increase in thermal conductivity above 400°C, it does not appear likely that this increase in thermal conductivity should be attributed to inaccuracy of measurement. The Creighton Mine rocks appear to be very competent and with strong intergranular bonds. It is possible therefore that at temperatures above 350°-400°C, a certain amount of microcrack healing takes place, which would result in increased overall thermal conductivity. That is, stresses, caused by shear and pressure forces in the original rock mass, may be relieved at ~350°C.

As seen in Figure 2, specimen CA-66 has about 10-15% higher thermal conductivity than the other three rocks. Although its grains are somewhat coarser than that of the others (with coarser grains and thus fewer interfaces, one would expect a higher thermal conductivity), the higher thermal conductivity of CA-66 cannot be attributed to the grain size because the variation in the thermal conductivity of rocks from the CB drill core, presented in Figure 3, cannot be related to either composition, texture or grain size.

The spread between the lowest and highest values for the rocks from the CB drill core is somewhat greater than that for the CA rocks. Also, the CB rocks have, on the average, slightly higher conductivity. However, from the point of view of nuclear waste storage, the most interesting feature shown by the rocks of both groups is the relatively low decrease of thermal conductivity with increasing temperature. (A rapid decrease of thermal conductivity with increasing temperature is a factor significantly contributing to thermal instability of the rock repository. Should the temperature of the repository increase above the expected level, the increase would cause a decrease of thermal conductivity lowering its ability to conduct the heat and in turn raising the temperature of the repository still further, and so on.) This can be seen best in Figure 4, where the shaded area, representing the thermal conductivity of Creighton Mine rocks, is superimposed on thermal conductivity curves of different rocks used in a previous study[4]. Two rocks in this group, chloritized amphibolite and granodiorite, are foliated rocks and their thermal conductivities are shown for measurements performed parallel (upper curve) and perpendicular to the schictosity. The area shaded with vertical dotted lines denotes the range of thermal conductivities of the CA rocks, whereas the area shaded with horizontal dotted lines represents the thermal conductivity of the CB rocks.

In comparison with the other rocks shown in Figure 4, the thermal conductivity of the CA and CB specimens is average, but at 500°C it equals or even exceeds that of the rocks with highest thermal conductivity. In this regard, the Creighton Mine

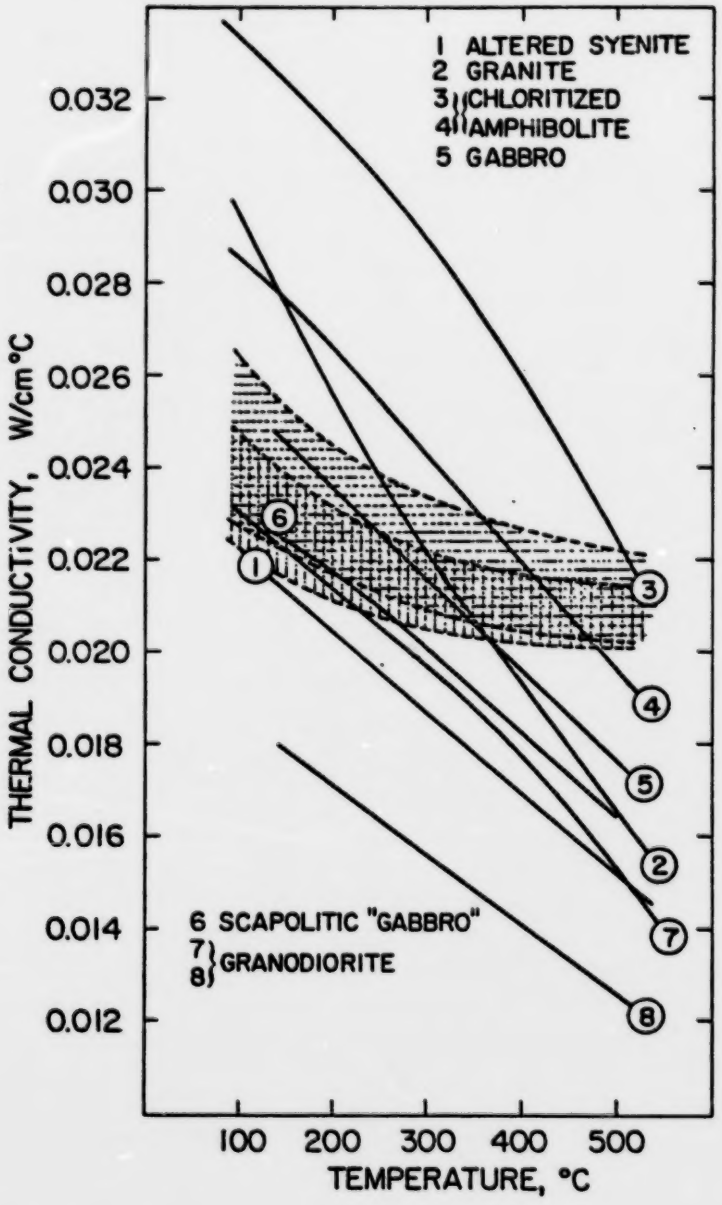


Figure 4. Comparison between the thermal conductivities of Creighton Mine rocks from drill cores CA and CB, and eight different rock specimens[4].

specimens differ considerably from the other rocks and it can be expected therefore that the thermal stability of a nuclear waste repository located in a CA-CB type rock mass would be appreciably higher than one placed in rock masses represented by the other specimens in Figure 4.

It should be noted, however, that rocks 1 to 8 were collected at the surface, whereas the Creighton Mine rocks were obtained from deep underground. While exposed at the surface to the effects of weather, possibly for centuries, the intergranular bonds of specimen 1 to 8 could have weakened. On heating, during the measuring process, the microcracks would open more readily and in turn, cause the observed precipitous decrease of thermal conductivity with increasing temperature.

Finally, it must also be observed that all of these thermal conductivity measurements were performed in unconstrained conditions. Such figures are valid for rocks at the surface and immediately near the surface of the repository because there the pressures are relieved. However, at any other distance from the surface of the repository, where the rock mass could be under a pressure of several kilobars, the thermal conductivity values obtained in the present measuring mode would not correspond to the actual values. Consideration should therefore be given to performing thermal conductivity (or perhaps thermal diffusivity) measurements, on at least some of the rocks, under high isostatic pressures.

## CONCLUSIONS

The results of thermal conductivity measurements on Creighton rock specimens show a substantially lesser decrease of thermal conductivity with increasing temperature than that of other rocks. This indicates that a nuclear waste repository of better thermal stability would be attained in the Creighton Mine type rock mass than in the other types of rocks measured to date.

In addition to unconstrained thermal conductivity measurements, thermal conductivity measurements of some rocks should be performed at high pressure.

## REFERENCES

1) Horai, Ki-iti. "Thermal conductivity of rock-forming minerals"; J. Geophys. Res.; 76, 5, 1278-1308; 1971.

2) Mirkovich, V.V. "Comparative method and choice of standards for thermal conductivity determinations"; J. Am. Cer. Soc.; 48, 8, 387-91; 1965.

3) Soles, J.A. "Nuclear waste repository studies: petrography at the site of an in-situ heater experiment, Creighton Mine, Ontario"; CANMET; Mineral Sciences Laboratories Report MRP/MSL 78-13 (CF); 1978.

4) Mirkovich, V.V. and Soles, J.A. "Thermal conductivity of rock types and its relevance to the storage of nuclear waste"; Thermal Conductivity 15, ed. by Vladimir V. Mirkovich, Plenum Press, New York and London; 1978.

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